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Specification and Drawings, as originally filed, with Application for Patent Serial No: **2,401,474**, on September 5, 2002, by **ECOLE DE TECHNOLOGIES SUPÉRIEUR.**, assignee of Fernand Careau and Hugues Maltais, for "Drive Roller Control for Toric-Drive Transmissions ".

Agent certificateur/Certifying Officer

September 9, 2003

Date

# DRIVE ROLLER CONTROL FOR TORIC-DRIVE TRANSMISSION

## TECHNICAL FIELD

[0001] The present invention generally relates to a toric-drive continuously variable transmission and, more particularly, to a drive roller control for use therewith.

## BACKGROUND ART

[0002] Transmissions are used in motorized vehicles to transmit the engine power to the propelling system of the vehicles (i.e., wheels, propellers, etc.). Various types of transmissions adapt to the different engines and motors in order to propel the vehicle. An internal combustion engine, for instance, does not behave like an electric motor. An electric motor evolves between a full stop to high running speeds at high efficiencies. Therefore, a transmission may couple the electric motor directly to the propelling system. An internal combustion engine, on the other hand, will not run below a minimal revolutions per minute (RPM) and is also limited with respect to the maximal RPM it may attain. Therefore, the transmission used with such engines requires a clutching mechanism in order to allow the internal combustion engine to run while the vehicle is idle. Furthermore, the transmission must allow ratio changes between the engine output and the propelling system input, as high torque is typically required initially to propel the idle vehicle forward, to the detriment of the vehicle speed. Thereafter, lower torque is supplied for higher speed.

[0003] There are generally two main types of transmissions for internal combustion engine vehicles in the automotive industry: the discontinuous ratio transmission and the continuously variable transmission (CVT). The difference between the two types of transmission is comparable to the relation, in mathematics, between integers and real numbers. There are five integers comprised between

1 and 5 inclusively, whereas there is an infinity of real numbers between the same interval. The translation from an integer to the next integer implies a jump, a discontinuity. A discontinuous ratio transmission has such jumps. For instance, a five-speed vehicle has five different ratios, the ratio being the rotational speed at the inlet divided by the rotational speed at the outlet of the transmission. On the other hand, CVT's have an infinite ratio of speeds between inlet and outlet of the transmission, extending between a minimal ratio and a maximal ratio.

[0004] Discontinuous ratio transmissions are found on most cars, as they are highly efficient (in the vicinity of 95%) and highly reliable as there are no efficiency losses due to slip or overheating, and these transmissions are closed from water and dust damage. On the other hand, the discontinuity between the speed ratios and the necessity for clutching to switch speeds are major inconveniences. There is a loss in engine power, although small, when switching from one ratio to another. These transmissions also are more complex and require synchronization between the ratio changes. Furthermore, in difficult conditions, driver ability comes into account.

[0005] With CVT's, the change of speed and ratios is effected without discontinuity. The CVT's are also very flexible in allowing to optimize the use of the engine to which they are connected. However, CVT's are typically less energy-efficient than discontinuous ratio transmissions.

## SUMMARY OF INVENTION

[0006] Therefore, it is a feature of the present invention to provide a continuously variable transmission having an increased energy efficiency.

[0007] According to the above feature of the present invention, and from a broad aspect thereof, the present invention provides a toric-drive transmission comprising a drive disk adapted for receiving a drive input from

actuation means. A driven disk is opposite the drive disk and adapted for transmitting motion to output means. Drive rollers are between the drive disk and the driven disk. The drive rollers have three rotational degrees of freedom. A first one of the rotational degrees of freedom is for transmitting motion from the drive disk to the driven disk. A second one of the rotational degrees of freedom changes an input-to-output ratio between the drive disk and the driven disk. A third one of the rotational degrees of freedom initiates rotation about the second one of the rotational degrees of freedom. Control means are provided for controlling motion of the drive rollers in the second and third ones of the rotational degrees of freedom.

## BRIEF DESCRIPTION OF DRAWINGS

[0008] A preferred embodiment of the present invention will now be described with reference to the accompanying drawings in which:

[0009] Fig. 1 is an exploded view of a toric-drive transmission in accordance with the present invention;

[0010] Fig. 2 is a perspective view of a drive disk and a driven disk in accordance with the present invention;

[0011] Fig. 3 is a perspective view of a drive roller in accordance with the present invention;

[0012] Fig. 4 is a perspective view of a structure elbow in accordance with the present invention;

[0013] Figs. 5A to 5C are schematic sectioned views of the toric-drive transmission; and

[0014] Fig. 6 is a graph illustrating the speed vs. the RPM of a CVT in comparison with a discontinuous-drive transmission.

## DESCRIPTION OF PREFERRED EMBODIMENTS

[0015] Referring now to the drawings and more particularly to Fig. 1, a toric-drive transmission in accordance with the present invention is generally shown at

10. A protective casing, along with the necessary seals and joints, have been removed from the figures in order to clarify the views of the transmission 10. The toric-drive transmission 10 of the present invention is protected from dust and water, as it is enclosed in the casing (not shown). The various elements of the transmission 10 are shown exploded. A drive axis is generally shown at D.

[0016] The transmission 10 comprises a drive disk 12. As seen in Figs. 1, 2 and 5A to 5C, the drive disk 12 has a groove 14 which is a portion of a torus. The drive disk 12 has on an opposed side a flange 16 extending axially with three connection slots 18 therein. A driven disk 22 is a mirror image of the drive disk 12. The driven disk 22, therefore, also has a groove 24 which is a portion of a torus, and on an opposed side a flange 26 having three connection slots 28. The drive disk 12 and the driven disk 22 are positioned in the transmission 10 such as to have the grooves 14 and 24 facing each other, and this is well depicted in Figs. 2 and 5A to 5C.

[0017] Referring now to Fig. 3, a drive roller is shown at 30. The drive roller 30 is disk-shaped and has a peripheral surface 32. The peripheral surface 32 is slightly convex. The drive roller 30 is held in a drive roller support 34. The drive roller support 34 consists of a pair of parallel plates 36 spaced from one another to receive the driver roller 30 therebetween. A shaft (not shown) serves as an axle for the drive roller 30 and is held at opposed ends by the parallel plates 36. Bearings (not shown) ensure the rolling of the drive roller 30 about the axle held by the parallel plates 36. Opposed ends of the parallel plates 36 each comprise a head 38, which has a spherical contact surface 40, from which guide pins 42 extend from the middle thereof. One of the two parallel plates 36 has a control arm 44 with a follower sphere 46 at an end thereof. As seen in Fig. 1, the follower sphere 46 is adapted for being received in a socket 48. Each of the

sockets 48 is tube-shaped. It is observed in Fig. 1 that the transmission 10 has three drive rollers 30, each mounted to a drive roller support 34. It is pointed out that the transmission 10 of the present invention may be provided with various configurations ranging from one drive roller to a plurality of drive rollers.

[0018] Referring now to Figs. 5A to 5C, two drive rollers 30 are shown in various positions between the drive disk 12 and the driven disk 22 in order to illustrate the operation of the toric-drive transmission 10. The drive rollers 30 are driven by the drive disk 12 and, therefore, transmit the rotative motion to the driven disk 22. The drive rollers 30 rotate about an X-axis in the transmittal of the rotative motion from the drive disk 12 to the driven disk 22. The drive rollers 30 may also rotate about the Z-axis in order to change the input-to-output ratio of the transmission 10. The drive roller 30 transmits the rotating motion from the drive disk 12 to the driven disk 22 by being in contact, through its peripheral surface 32, with thin films of oil on the surfaces of the grooves 14 and 24. This will be described in further detail hereinafter. The drive rollers 30 have a third rotational degree of freedom, as they may rotate according to the Y-axis. The Y-axis extends between the point of contact of the drive disk 12 with the drive roller 30 and the point of contact of the drive roller 30 with the driven disk 22. The rotation about the Y-axis will initiate the Z-axis rotation, which will modify the input-to-output ratio. This will be explained in further detail hereinafter.

[0019] According to Fig. 5A, the transmission 10 is in speed reduction. In speed reduction, the input-to-output ratio is above 1 as the drive disk 12 (input) rotates faster than the driven disk 22 (output). As the distance R1 from the point of contact between the drive disk 12 and the drive rollers 30 to the center of the drive disk 12 is smaller than the distance R2 from the point of contact between the

driven disk 22 and the driv roller 30 to the center of the driven disk 22, the drive disk 12 will rotate faster than the driven disk 22. A rotation of the drive rollers 30 about their respective Z-axes leads to other ratios, such as that shown in Figs. 5B and 5C. Fig. 5B illustrates a direct drive between the drive disk 12 and the driven disk 22. In the direct drive, the drive disk 12 and the driven disk 22 rotate at the same speed, giving a ratio of 1 between input (drive disk 12) and output (driven disk 22). This is achieved by distance R1 being equal to distance R2. Fig. 5C illustrates an overdrive between the drive disk 12 and the driven disk 22, and the ratio is therefore below 1. In this case, distance R1 is greater than distance R2, to have the driven disk 22 rotate faster than the drive disk 12. As mentioned above, a vehicle having the toric-drive transmission 10 of the present invention initially has the drive rollers 30 in a speed-reduction position. The input-to-output ratio at that point is above 1, which means that the output speed is below the input speed. Therefore, the torque of the engine is used to provide torque to the wheels. As the vehicle increases speed, the input-to-output ratio is gradually decreased in order to lessen the torque transmitted to the wheels while increasing the speed of the wheels.

**[0020]** Returning to Fig. 1, the toric-drive transmission 10 is shown with the three drive rollers 30, each having a drive roller support 34. For simplicity purposes, each drive roller 30/drive roller support 34 assembly will be referred to hereinafter as assembly 35. Assemblies 35 are each supported between structure elbows 50. The toric-drive transmission 10 has three structure elbows 50 in order to support all three assemblies 35. As best seen in Fig. 4, each structure elbow 50 has an arcuate flange 52, by which it is secured to the casing (not shown) of the transmission 10. The structure elbows 50 are structural, and are thus immovable in the transmission 10.

The structure elbows 50 each have an arcuate body 54 from which the arcuate flange 52 projects outwardly. On opposed ends, the arcuate body 54 has spherical contact surfaces 56. The spherical contact surfaces 56 of the structure elbows 50 are adapted for receiving in a coplanar and sliding relationship the spherical contact surfaces 40 of the driver roller supports 34. Therefore, the assemblies 35 may move with respect to the structure elbows 50, which, as mentioned above, are idle in the transmission 10. The spherical contact surfaces 56 each have a channel 58 therein in order to receive the guide pins 42 of the spherical contact surfaces 40. The drive rollers 30 of the assemblies 35 may thus pivot about the Z-axis direction. Furthermore, translation of the assemblies 35 in the channels 58 (via guide pins 42 of the drive roller supports 34) causes rotation of the drive rollers 35 about their respective Y-axes.

[0021] Y-axis and Z-axis rotations of the drive rollers 30 will cause changes to the input-to-output ratio of the transmission 10. The control of the Y-axis and Z-axis rotations is achieved by three sleeves: an internal sleeve 60, a drive-mode external sleeve 66, and a reverse-mode external sleeve 72.

[0022] The internal sleeve 60 is tube-shaped with three equidistantly spaced holes 62 therein. The holes 62 are adapted to immovably hold the sockets 48. As mentioned above, the sockets 48 host the follower spheres 46 of the drive roller supports 34. The internal sleeve 60 further comprises three rectangular openings 64. The openings 64 are equidistantly spaced on the periphery of the internal sleeve 60. When the transmission 10 is assembled, the arcuate flanges 52 of the structure elbows 50 extend through the openings 64 of the internal sleeve 60. The internal sleeve 60 has two degrees of freedom. First, the internal sleeve 60 may translate with respect to the drive axis D, wherefore th openings 64 are rectangular and not elongated

so that the structure elbows 50 do not interfere with the translation of the internal sleeve 60. Second, the internal sleeve 60 can rotate about the drive axis D. Therefore, the openings 64 are longer than the arcuate flanges 52, and the rotational displacement of the internal sleeve 60 is limited by the abutting of the sides of the opening 64 with the arcuate flange 52 (e.g., 4° of play in rotation). The rotation of the internal sleeve 60 with respect to the drive axis D will rotate the drive rollers 30 about their Y-axes, i.e., as the internal sleeve 60 rotates, the sockets 48, which are secured in the holes 62, will guide the drive rollers 30 in rotating about their respective Y-axes, as the follower spheres 46 which follow the movement of the sockets 48. This rotation is possible, as mentioned above, by the channels 58 in the structure elbows 50 guiding the guide pins 42. As the channels 58 are oriented in the same direction as the rotation of the internal sleeve 60, the assemblies 35 may be driven into rotating about the Y-axis by a rotation of the internal sleeve 60, thereby making the drive rollers 30 rotate in the Y-axis.

[0023] On the other hand, a translation of the internal sleeve 60 along the drive axis D will have the drive rollers 30 rotate in their respective Z-axes. The internal sleeve 60 will rotate the drive rollers 30 through the action of the sockets 48 on the follower spheres 46. More specifically, the drive roller supports 34 will each pivot with respect to the structure elbows 50, as the guide pins 42 will pivot in the channels 58. It is pointed out that the coplanar engagement of the spherical contact surfaces 56 of the structure elbows 50 and the spherical contact surfaces 40 of the drive roller supports 34 enable this rotation of the assemblies 35 with respect to the structure elbows 50.

[0024] The drive-mode external sleeve 66 is tube-shaped and has an internal diameter slightly larger than the external diameter of the internal sleeve 60, so as to be in

sliding contact therewith. The drive-mode external sleeve 66 has three obround openings 68 which are equidistantly spaced and are each of the same dimensions. The drive-mode external sleeve 66 further comprises helical channels 70 between adjacent obround openings 68. The obround openings 68 are adapted for receiving therethrough the arcuate flanges 52 of the structure elbows 50. As the obround openings 68 are only slightly larger than the arcuate flanges 52, the drive-mode external sleeve 66 is limited to one degree of freedom, in rotation, about the drive axis D. The helical openings 70 are adapted for receiving therein a portion of the sockets 48. With the orientation of the helical openings 70, and the fact that the drive-mode external sleeve 66 is kept from moving in translation on the drive axis D, a rotation of the drive-mode external sleeve 66 will have the internal sleeve 60 translating about the drive axis D as the sockets 48 will move upward or downward in the helical openings 70. As mentioned earlier, a translation of the internal sleeve 60 on the drive axis D will have the drive rollers 30 rotating in the Z-axis.

[0025] The reverse-mode external sleeve 72 has an internal diameter slightly greater than the external diameter of the drive-mode external sleeve 66, so as to be in sliding contact therewith. The reverse-mode external sleeve 72 also has obround openings 74 which are equidistantly spaced on the periphery of the reverse-mode external sleeve 72. Helical openings 76 are positioned between adjacent ends of obround openings 74. However, when compared with the drive-mode external sleeve 66, the helical openings are oriented in an opposite direction. The helical openings 76 are adapted for receiving therein a portion of the sockets 48, whereas the obround openings 74 receive the arcuate flanges 52 therethrough such that the reverse-mode external sleeve 72 is restricted in rotating about the drive axis D, i.e., has one degree of freedom. Once more, a rotation of the reverse-mode external sleeve 72 will be

transformed into a translation motion of the internal sleeve 60 (through the sockets 48 engaging displacements in the helical openings 76), and thus into a rotation of the drive rollers 30 in the Z-axis.

[0026] Still referring to Fig. 1, the toric-drive transmission 10 is provided with various gears and shafts to receive the driving input from the engine and output the transmitted motion to the wheels. It is pointed out that the toric-drive transmission given as an example in Fig. 1 has both the input and output on the same side. The toric-drive transmission 10 may also be provided with the input on one side and the output on the other side. The same-side input/output mechanisms, which will be described briefly hereinafter, are only provided for describing an embodiment of the present invention, and are by no means limitative. The input from the engine (not shown) is received by gear 100. The gear 100 has teeth 102 at a front end thereof for meshing with a gear at the output of the engine, and has claws 104 projecting outwardly from a flanged portion thereof. The claws 104 mate with the connection slots 18 (Fig. 2) in the drive disk 12 so as to rotate therewith. A bearing 106 is sandwiched between the gear 100 and the drive disk 12 and will support both the gear 100 and the drive disk 12 on a driveshaft 108. Spacers 110 are received in the gear 100 and allow the latter to rotate freely about the driveshaft 108.

[0027] The driveshaft 108 is elongated and has at a first end thereof threads 112 and splines 114. The other end of the driveshaft 108 is equipped with a gear portion 116. When the toric-drive transmission 10 is assembled, with the rollers 30 in contact with both the drive disk 12 and the driven disk 22, the driveshaft 108 extends beyond the driven disk 22 such that the spline 114 and the threads 112 emerge outwardly therefrom. A transmission ring 118, having a through bore comprising slots corresponding to splines 114, is secured to the splines 114 of the driveshaft

108. The transmission ring 118 has claws 120, which mate with the connection slots 28 of the driven disk 22. Therefore, the transmission ring 118 rotates with the driven disk 22. Furthermore, as the transmission ring 118 is secured to the spline 114 of the driveshaft 108, the driveshaft 108 rotates with the driven disk 22. A nut 122 which is tapped is received on the threads 112 of the driveshaft 108 and ensures that the transmission ring 118 stays on the driveshaft 108 by pushing a washer 121 thereagainst. Furthermore, keys 124 ensure that the transmission ring 118 and the washer 121 rotate together, and thus that the nut 122 does not become loosened.

[0028] A Belleville spring 126 is sandwiched between the driven disk 22 and the transmission ring 118. The Belleville spring 126 consists of a ring of resilient material, whereby it may be squeezed so as to allow the driven disk 22 to translate on the drive axis D when engaged with the transmission ring 118. Therefore, the Belleville spring 126 provides the contact force in order for the driven disk 22 to be in contact with the drive rollers 30 at all times. The toric-drive transmission 10 does not require an overly large casing, as the contact force between the drive rollers 30 and the disks 12 and 22 is in the axial direction and is thus sustained by the driveshaft one way.

[0029] Now that the toric-drive transmission 10 has been described in detail, the steps for changing ratios will be described. For clarity purposes, all components rotating about the drive axis D will be referred to as turning in direction A, or in direction B, which is opposite direction A. Figs. 1 and 5A to 5C have been added with vectors A and B for illustrating the rotation direction. According to the driving mode of the vehicle, the drive disk 12 will be rotating in either direction A or B. If the vehicle is moving forward, the drive disk 12 will, for instance, be rotating in direction A upon receiving the engine output. When the drive disk 12 is rotating in direction A, the

driven disk 22 will b rotating in direction B, as a result of the transmitted rotation by the rollers 30. As mentioned above, in transmitting the rotation from dive disk 12 to driven disk 22, the rollers rotate about their respective X-axes.

[0030] Initially, the drive rollers 30 are in a speed reduction position within the transmission 10, as illustrated in Fig. 5A. In this position, the drive disk 12 rotates faster than the driven disk 22. In speed reduction, more torque is provided to the wheels, and this position is preferably used when the vehicle is idle or needs high torque. As the drive rollers 30 rotate about their Z-axes toward a direct drive (as shown in Fig. 5B), the input-to-output ratio gradually decreases and, in doing so, the driven disk 22 increases speed with respect to the drive disk 12.

[0031] When the vehicle is in the drive mode, the drive-mode external sleeve 66 will be active in allowing to change speed ratios between the drive disk 12 and the driven disk 22 while the reverse-mode external sleeve 72 is inactive. To increase the rotating speed of the driven disk 22, and thus reduce the input-to-output ratio, both the internal sleeve 60 and the drive-mode external sleeve 66 are rotated together in the A direction. This is achieved by the drive-mode external sleeve 66 being fixed temporarily to the internal sleeve 60 so as to rotate therewith. As a result, and as mentioned above, the drive rollers 30 will rotate about their respective Y-axes. More specifically, the internal sleeve 60 will guide the follower spheres 46 into rotating the assemblies 35, and the engagement of the guide pins 42 in the channels 58 allows this pivoting. In other words, the assemblies 35 will slide against the spherical contact surfaces 56 while being guided by their respective pins 42 following the paths defined by the channels 58, and thus having the rollers 30 rotate with respect to their Y-axes. This will result in the rollers

30, which were defining a circular path on the drive disk 12 and the driven disk 22 (i.e., R1 and R2 remaining constant), changing to a spiral path on the drive disk 12 and the driven disk 22 (i.e., with, in this case, R1 continuously decreasing while R2 continuously increases). In taking a spiral path, the rollers 30 will further pivot with respect to their Y-axes. Immediately after the internal sleeve 60 and the drive-mode external sleeve 66 have been rotated together in A to initiate the spiral path of the rollers 30, the internal sleeve 60 is detached from the drive-mode external sleeve 66, and the drive-mode external sleeve 66 is fixed with respect to the toric-drive transmission 10. Once in the spiral path, the rollers 30 will have a tendency to move back to their initial Y-axis position, i.e., as they were prior to being displaced by the internal sleeve 60/external sleeve 66 rotation. They will thus exert axial force on the internal sleeve 60 and the drive-mode external sleeve 66 in order to return to that Y-axis orientation. As the sockets 48 are immovably secured to the internal sleeve 60, this force exerted by the drive rollers 30, to move out of their spiral pattern, will be exerted on the drive-mode external sleeve 66, which, as mentioned above, is now fixed and immovable with respect to the toric-drive transmission. Since the sockets 48 are in the helical openings 70, a return of the drive rollers 30 to their initial Y-axis orientations will displace the sockets 48 in the direction of arrow 1 in the helical opening 70. As the drive-mode external sleeve 66 is immovable, this will result in the internal sleeve 60 moving toward the driven disk 22 in the D-axis direction, i.e., to the left in Fig. 1. This will cause the drive rollers 30 to rotate in their respective Z-axes as a result thereof and, therefore, to move to decrease the input-to-output ratio toward a direct-drive position, as illustrated in Fig. 5B, or an overdrive position, as shown in Fig. 5C.

[0032] To increase the input-to-output ratio when the drive disk 12 is in the drive mode, i.e., rotates in A, the rotation of the drive-mode external sleeve 66 fixed to the internal sleeve 60 would be opposite, and thus in the B direction. This will cause the sockets 48 to move in the direction opposite arrow 1 in the helical openings 70, as shown in Fig. 1

[0033] Throughout the changes of ratios in the drive mode of the toric-drive transmission 10, the reverse-mode external sleeve 72 is unrestricted from rotating about the D-axis, to comply with the motion of the sockets 48 in the helical openings 70 of the drive-mode external sleeve 66. If the toric-drive transmission 10 were in reverse mode, the drive-mode external sleeve 66 would be unrestricted from rotating about the D-axis, while the reverse-mode external sleeve 72 would be controlled as described above for the drive-mode external sleeve 66. In the case of the reverse mode, the drive disk 12 will be rotating in direction B, obviously, and the driven disk 22 will thus be rotating in direction A. Accordingly, with the same logic as for the drive mode explained above, the initiating of a decrease in the input-to-output ratio will be achieved by a rotation of the reverse-mode external sleeve 72 fixed to the internal sleeve 60 in the B direction, whereas an A-direction rotation would cause an increase in the input-to-output ratio.

[0034] An advantage of the present invention resides in the fact that no great forces need to be applied to the drive rollers in order to initiate input-to-output ratio changes. As mentioned above, the initiation of the ratio change is achieved by rotating the internal sleeve 60, which is fixed to either the drive-mode external sleeve 66 or the reverse-mode external sleeve 72. Therefore, there is no need for a hydraulic control in order to initiate the ratio changing. The toric-drive transmission 10 of the present invention is thus advantageous when used with vehicles

CLAIMS:

1. A toric-drive transmission comprising:
a drive disk adapted for receiving a drive input from actuation means;
a driven disk opposite said drive disk and adapted for transmitting motion to output means;
at least one drive roller between said drive disk and said driven disk, said drive roller having three rotational degrees of freedom, a first one of said rotational degrees of freedom for transmitting motion from said drive disk to said driven disk, a second one of said rotational degrees of freedom for changing an input-to-output ratio between said drive disk and said driven disk, and a third one of said rotational degrees of freedom for initiating rotation about said second one of said rotational degrees of freedom; and
control means for controlling motion of said drive rollers in said second and third ones of said rotational degrees of freedom.

DRIVE ROLLER CONTROL
FOR TORIC-DRIVE TRANSMISSION


## ABSTRACT

A toric-drive transmission comprising a drive disk adapted for receiving a drive input from actuation means. A driven disk is opposite the drive disk and adapted for transmitting motion to output means. Drive rollers are between the drive disk and the driven disk. The drive rollers have three rotational degrees of freedom. A first one of the rotational degrees of freedom is for transmitting motion from the drive disk to the driven disk. A second one of the rotational degrees of freedom changes an input-to-output ratio between the drive disk and the driven disk. A third one of the rotational degrees of freedom initiates rotation about the second one of the rotational degrees of freedom. Control means are provided for controlling motion of the drive rollers in the second and third ones of the rotational degrees of freedom.

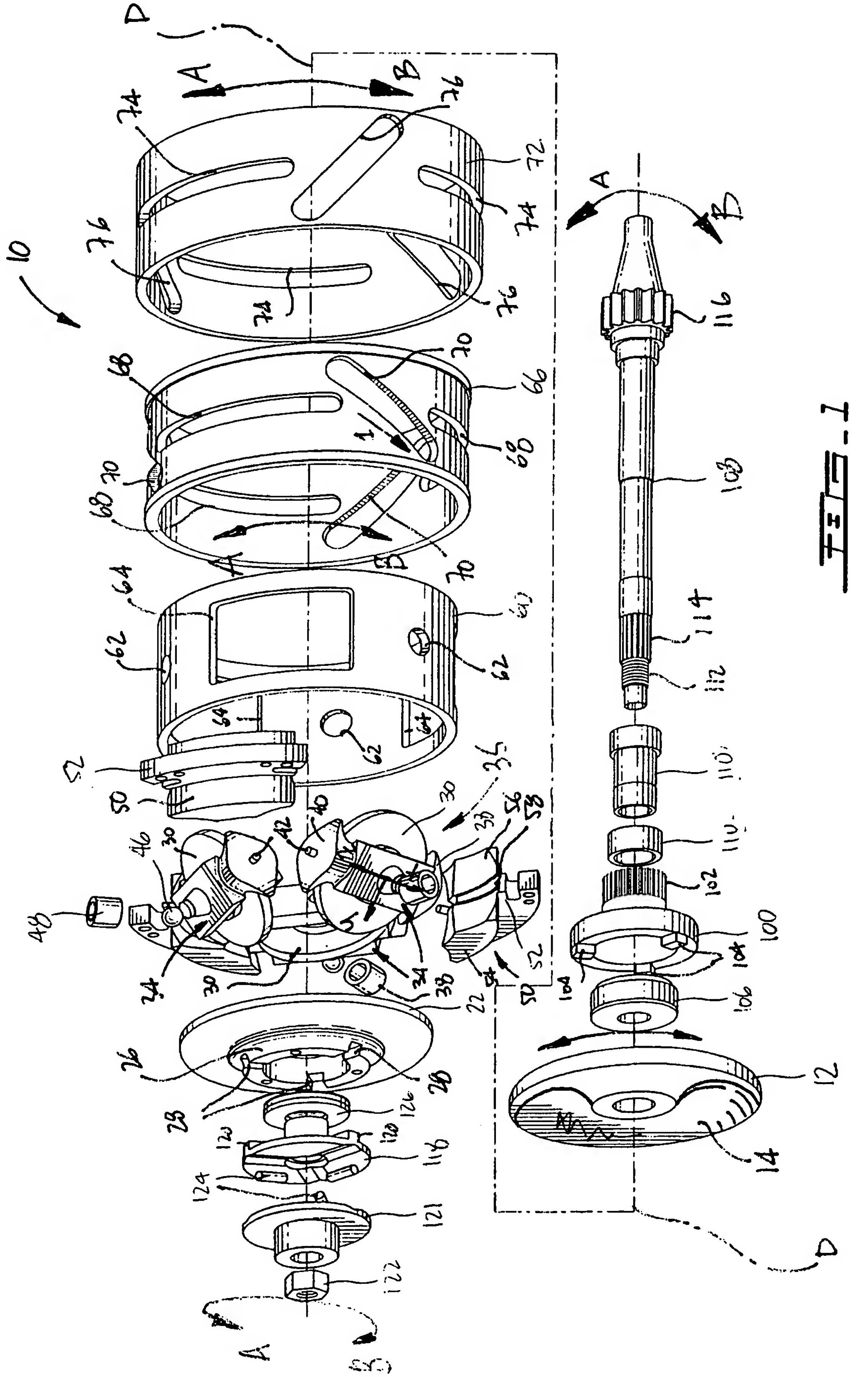


FIG. 1

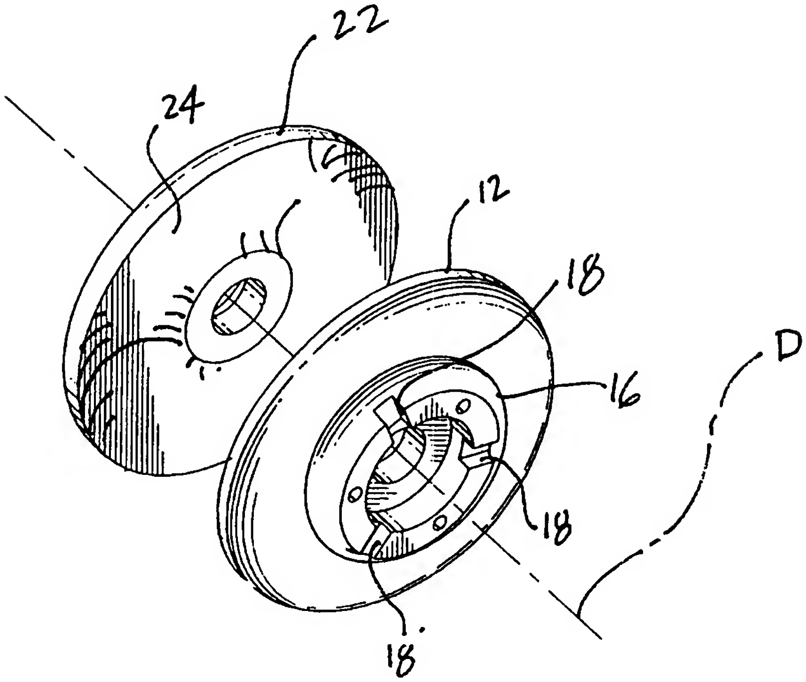



FIG. 2

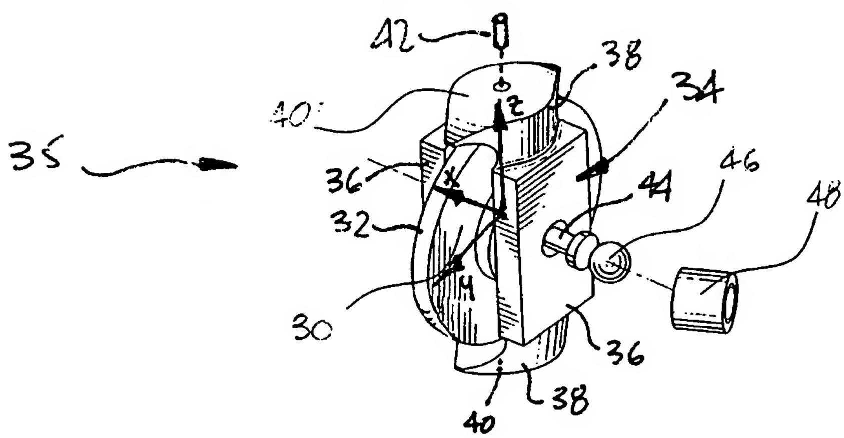



FIG. 3

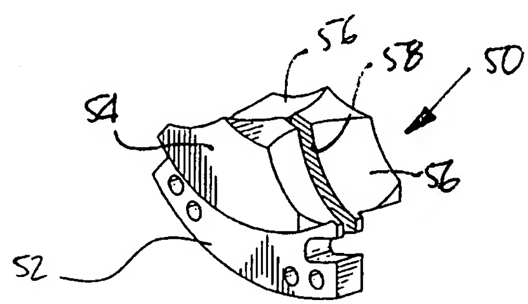



FIG. 4

FIG 5A

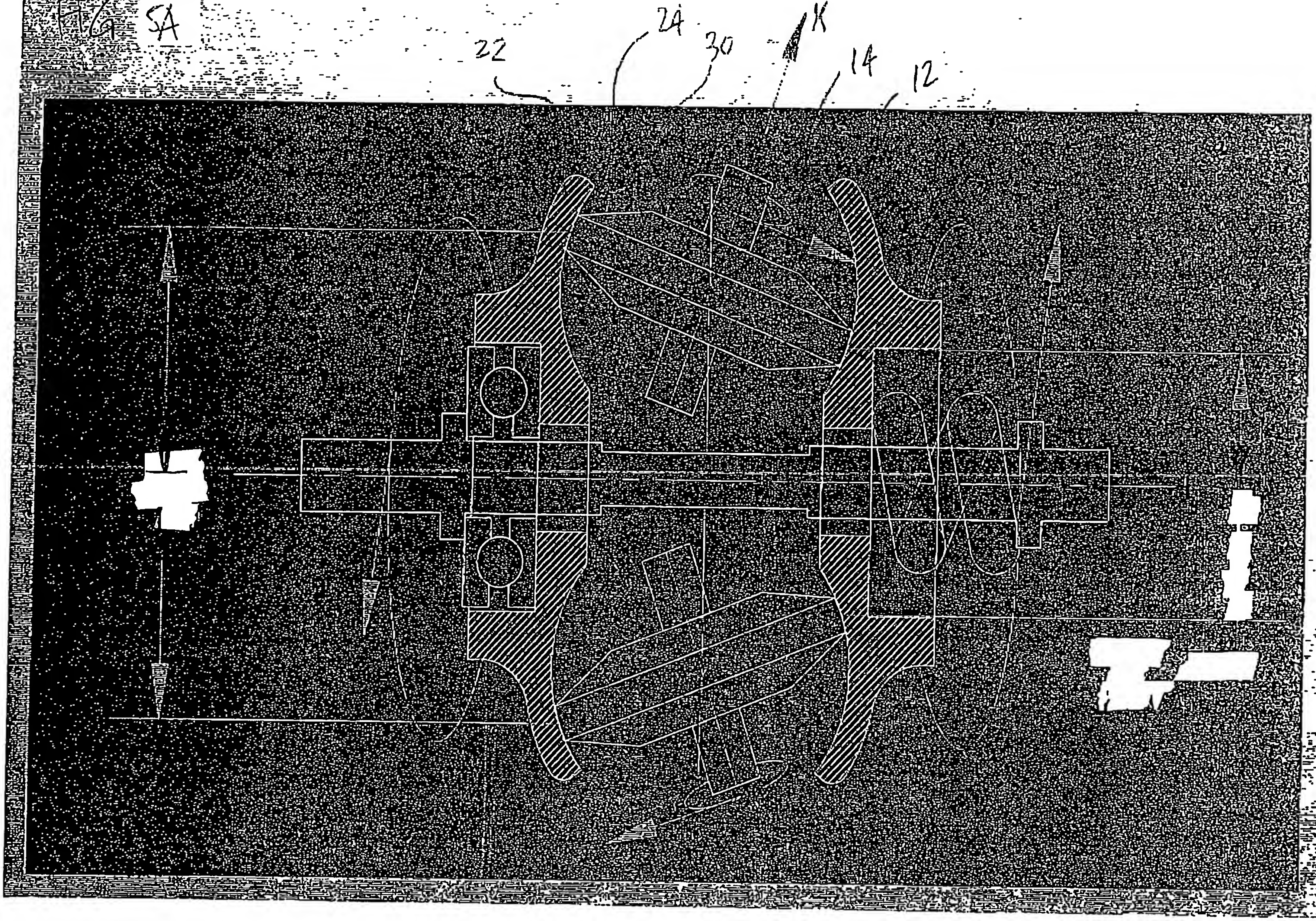


FIG. 5B

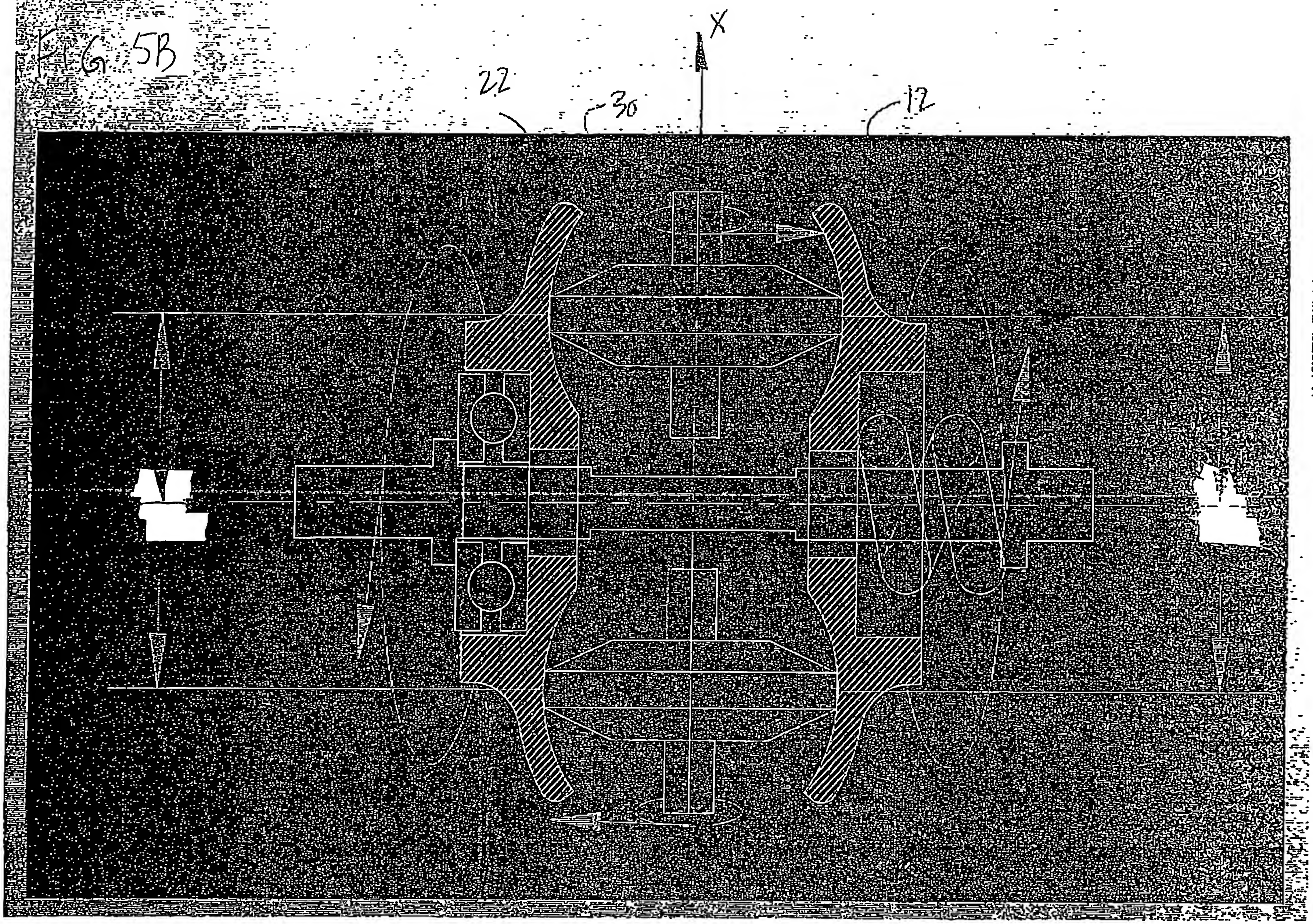
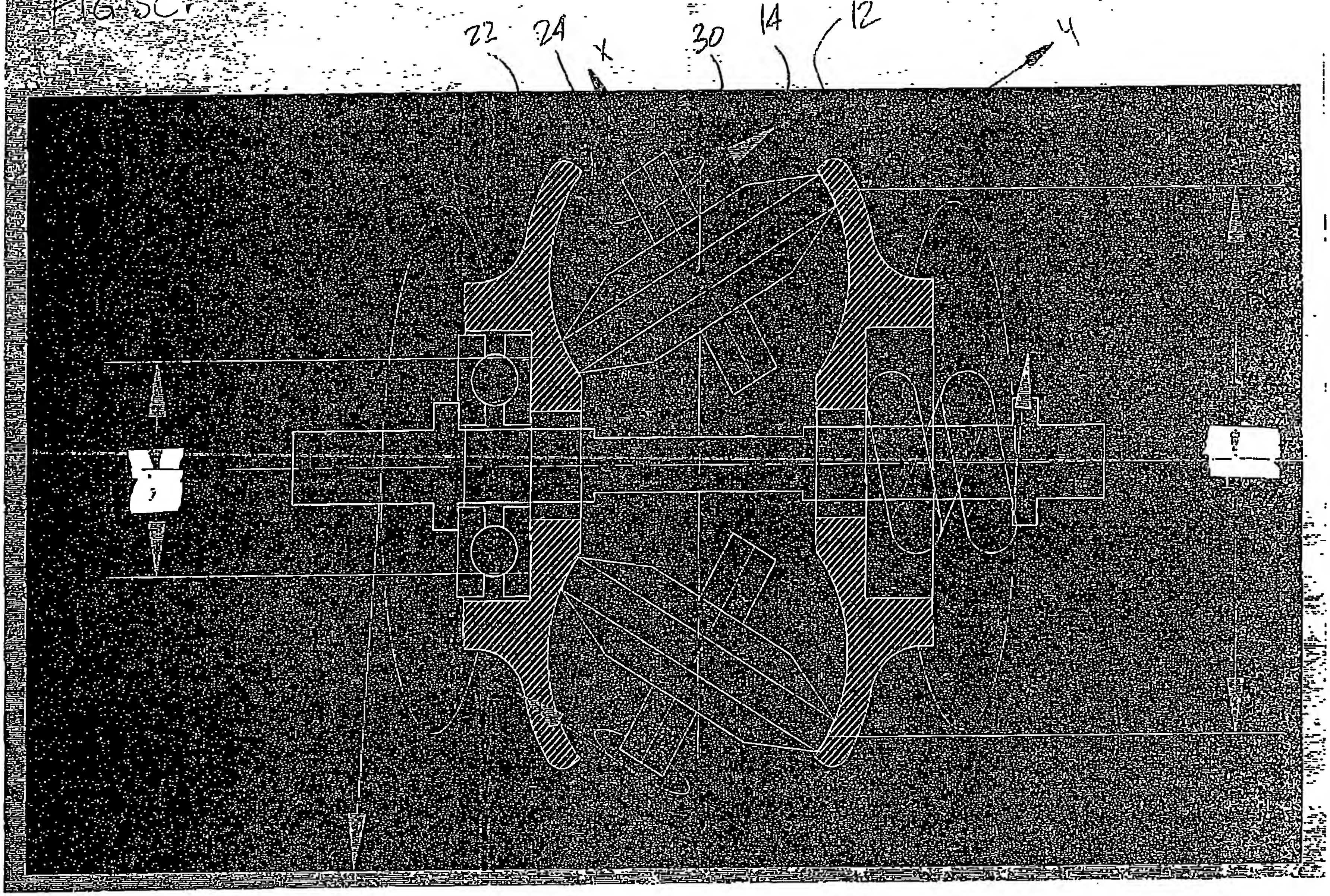


FIG 5C



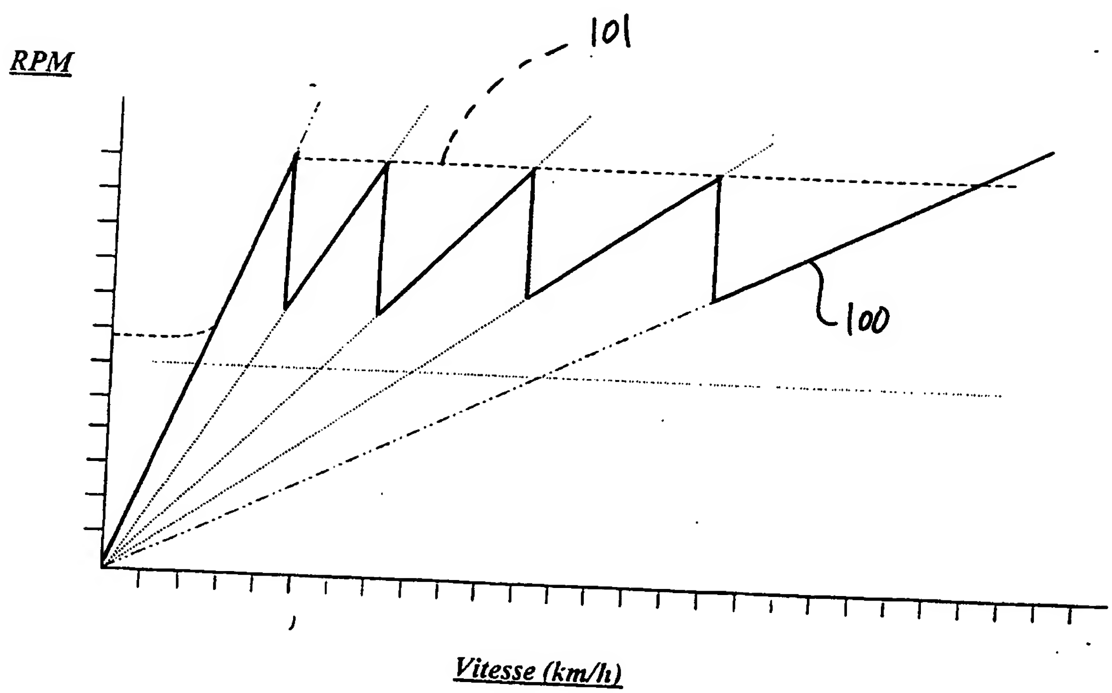



FIG. 6